Numerical Modeling of RF Propagation Over Rough Ocean Surface

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LONG TERM GOALS

The long terms goals of the project are to develop efficient numerical schemes for the assessment of ocean surface roughness and atmospheric ducting on the strength of a received RF signal.

OBJECTIVES

The objectives of the proposed work are to develop and optimize parabolic equation based techniques for treating forward propagation on an electrically large rough surface. We propose to look at two specific tasks in the proposed work with the parabolic equation: (1) explore the use of complex refractive index for terminating the computational domain at large heights; (2) determine the equivalent impedance of a rough surface for capturing the specular wave.

APPROACH

After a computational model has been developed, we intend to validate and compare the results with the experimental results generated by the Tropospheric Propagation branch of SPAWARSYSCEN, San Diego under the measurement campaign RED. A graduate student, Zhiguo Lai, was supported through the grant to help carry out the current research work.

WORK COMPLETED AND RESULTS

In the first task, we studied the effectiveness of a complex refractive index in terminating the upper region of the computational domain in the split-step Fourier algorithm of the parabolic equation. Propagation over a flat surface using scanned-beam transmitting antenna was considered for this purpose. The split-step Fourier solution of the wide-angle parabolic equation over a flat conducting surface with Dirichlet boundary condition is [3]

$$U(x+\Delta x, z) = e^{-jk_0(\overline{m}-1)\Delta x} \int_0^{\infty} e^{j\left(k_0^2-\sqrt{k_0^2-p^2}\right)\Delta x} \widetilde{U}(x,p) \sin pz \, dp,$$

where U is the field in the spatial domain and $\widetilde{U}$ is the field in the transformed domain, $\overline{m}(x,z)$ is the modified refractive index, k_0 is the wavenumber of the RF signal, and (x,z) are the range and height coordinates, Fig. 1.

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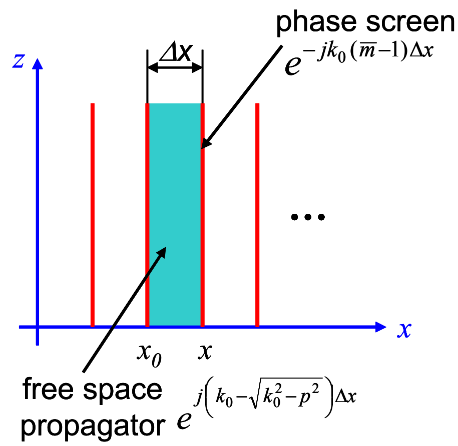

Fig. 1: Marching with wide-angle PE over a flat plane.

A Gaussian source with tilted beam is used at zero range to drive the problem. An absorbing layer with complex refractive index is used in the region $z_c \le z \le z_{\max}$

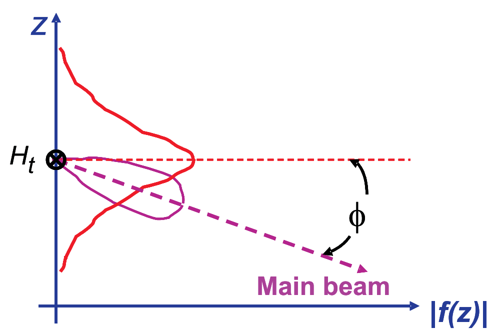

Fig. 2: A Gaussian source with tilted beam.

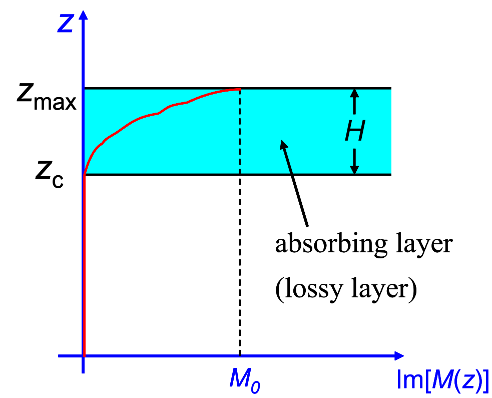

Fig. 3: Absorbing layer in $z_c \le z \le z_{\max}$

Several profiles shapes for the absorbing layer were chosen including a linear, quadratic and exponential. Fig. 4 shows comparison of the results with the analytical results generated by the 2-ray model. The results were rather insensitive to the profile shapes and good agreement is seen with the analytical model.

We also compared the results with those generated using a Hanning window [1]. In most cases the results with complex refractive index duplicated those generated with the Hanning window. However, cases were identified where the Hanning window fails to produce good results, while the complex refractive index continued to produce correct results as shown in Fig. 5. The incorrect results with Hanning window are believed to be caused by imperfect termination at the upper boundary, which the complex refractive index appears to have addressed. More test cases with propagation beyond the horizon are needed to confirm our initial conclusions.

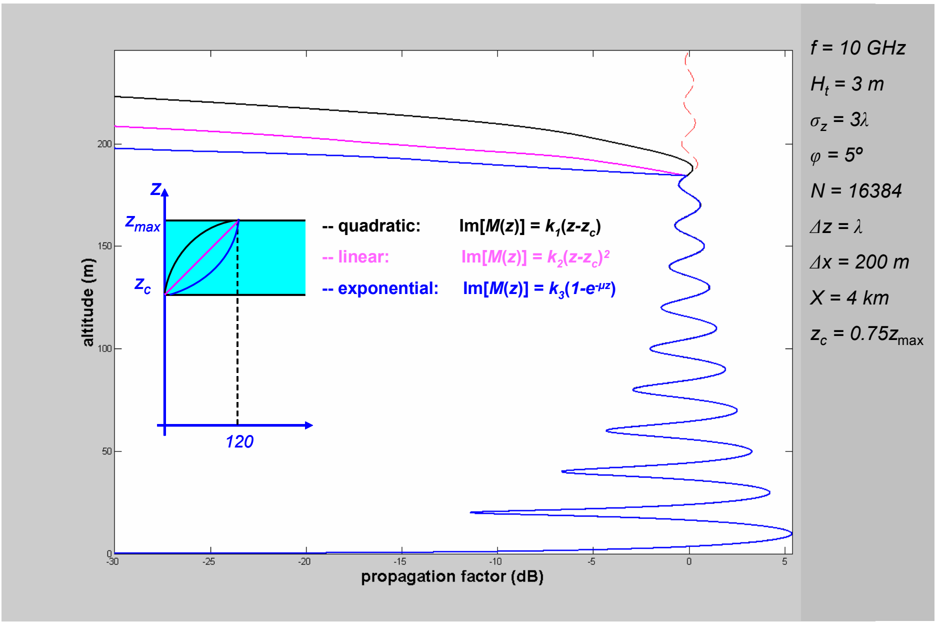

Fig. 4: Comparison of the propagation factor with the use of complex refractive index.

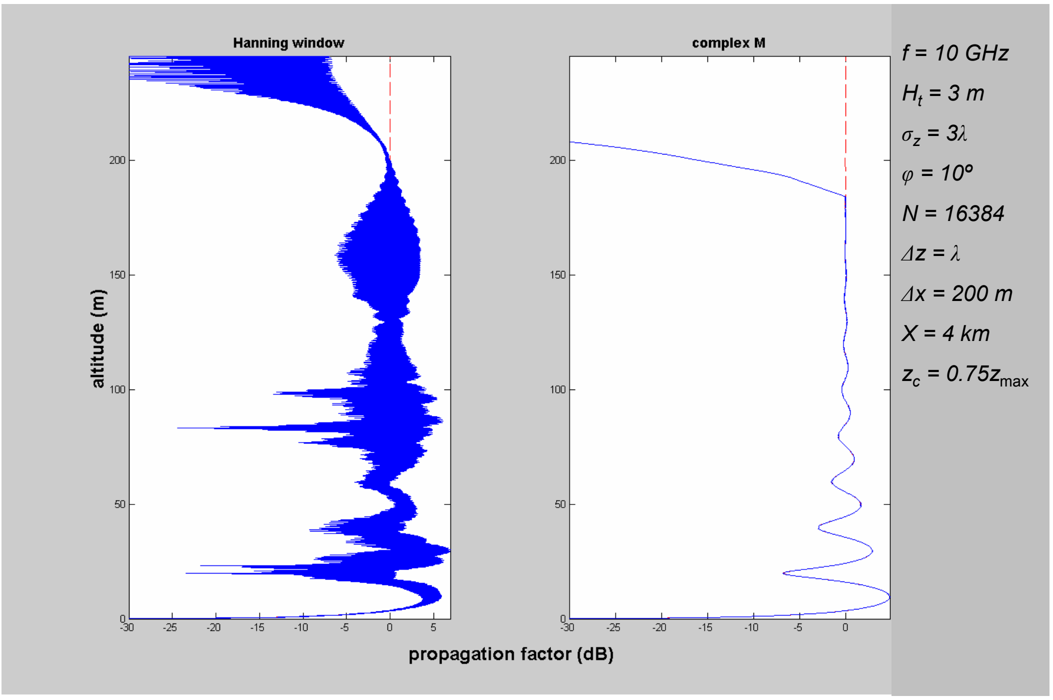

Fig. 5: Propagation factor with the use of complex refractive index versus the Hanning window.

IMPACT/APPLICATIONS

It is concluded that the complex refractive index approach can be used effectively to terminate the computational domain in practical PE codes.

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PUBLICATIONS

Z. Lai and R. Janaswamy, ``Use of complex refractive index for domain truncation in split-step PE solutions,'' paper URSI-F 35.5, 2003 Joint IEEE Antennas & Propagation International Symposium/URSI Meeting, Columbus, OH, June 22-27, 2003.